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HEAT REJECTION CAPABILITY FOR GEOSTATIONARY SATELLITES

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ABSTRACT

The aim of this study is to determine heat rejection capability on Geostationary satellites. When more dissipative communication equipments are added on satellites, there is always a need to reject heat into space environment. Therefore, increased heat rejection capability is important subject to be considered on satellites. In this study, heat rejection capability was studied on different shape of satellite radiators at given radiator temperature.

INTRODUCTION

Heat rejection systems for the satellite rely on the radiative surface areas to dissipate heat to space [Gilmore, 2002]. Radiators have specials coatings with a high emissivity and a low solar absorptivity. Increase surface of the radiative areas are exposure to the outer surface that is important element to thermal control of the satellite. The shape of the radiator influences directly the absorbed portion of solar heat power.

Energy balance requires that generated heat in the satellite plus absorbed heat from outside equals heat rejected to space. Therefore, determining the heat rejection capability is a key factor that has a significantly greater influence on thermal performance of the satellite.

DESCRIPTION OF SATELLITE HEAT REJECTION

The configuration of the satellite has been rectangular, square, etc. Heat rejection is performed by a thermal radiator, located on North and South panels of the rectangular or square three-axis stabilized satellite where the solar panels are mounted the satellite [Bulut, 2007]. Radiators placing on the north-south sides experience consistent thermal loading from day to day with respect to the sun. On the other hand, the thermal loading of the east-west sides are not consistent and fluctuate on daily base with respect to the sun. The satellite experiences wider temperature variations on the east-west sides than the north-south sides. Therefore, there is a need for a satellite body shape that utilizes heat rejection capability.

DESCRIPTION OF SATELLITE HEAT REJECTION

Temperature of different shapes in space environment

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The relation between temperature of the surface and heating in space is obtained from the conservation of energy as follows.

$$\int_{A^s} \alpha^s q^s dA^s = \int_{A^r} \varepsilon \sigma T^4 dA^r \qquad (1)$$

where A^s and A^r are the areas associated with incident and radiated energies and q^s is the solar energy. If the equation (1) is applied to the flat plate space, cylinder shape and sphere shape which are shown in Figure 1, the average temperature of the plate is defined by (plate radiating on one side only) in equation (2), for cylinder shape in equation (3), and sphere shape in equation (4)

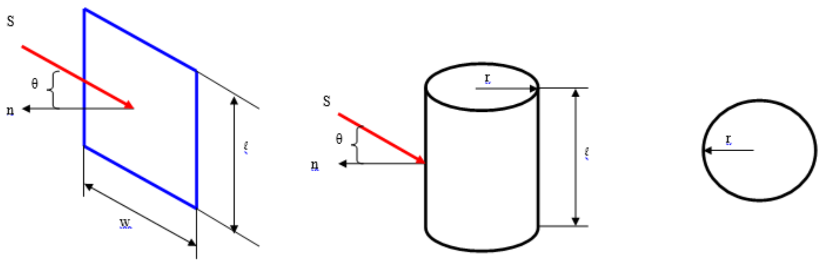


Figure 1: Flat plate, cylinder shape and sphere shape

$$T_{av(flatplate)} = \left[\frac{\alpha^s q^s}{\sigma \varepsilon} \right]^{\frac{1}{4}} \qquad (2)$$

$$T_{av(cylinder)} = \left[\frac{\alpha^s q^s}{\pi \sigma \varepsilon} \right]^{\frac{1}{4}} \qquad (3)$$

$$T_{av(sphere)} = \left[\frac{\alpha^s q^s}{4 \sigma \varepsilon} \right]^{\frac{1}{4}} \qquad (4)$$

In equations (2), (3) and (4), α^s is the absorptance of external surfaces, ε is emmitance of external surfaces, σ is Stephan-boltzmann, T is temperature of the external surface.

The average temperature T_{av} for each shape was calculated by equations (2), (3) and (4). The values in Table 1 were used for the calculation of T_{av}. The result is given in Table 2 and Table 3. T_s is deep space temperature.

Table 1: Properties of materials

Properties	**Values**
q_{ss}	1326 W/m^2
q_{ws}	1418 W/m^2
θ	0 deg
T_s	0 K

Properties	**Blackbody**	**White paint**	**Black paint**	**OSR**
α	1	0.2	0.94	0.27
ε	1	0.88	0.81	0.84

Table 2: Temperature comparison between different surface shapes and different surface materials at summer solstice (q_{ss}=1326 W/m^2)

q_{ss}= 1326 W/m^2 — Summer Solstice

		Black body	White paint	Black paint	OSR
	α	1	0,2	0,94	0,27
	ε	1	0,88	0,81	0,84
	α/ε	1	0,23	1,16	0,32
Surface	A^s/A	Steady-State Temperature T_{av} (°C)			
Flat plate	1,00	118	-3	133	21
Cylinder	0,32	21	-70	32	-52
sphere	0,25	3	-82	14	-65

Table 3: Temperature comparison between different surface shapes and different surface materials at summer solstice (q_{ss}=1418 W/m^2)

q_{ws}= 1418 W/m^2 — Winter Solstice

		Black body	White paint	Black paint	OSR
	α	1	0,2	0,94	0,27
	ε	1	0,88	0,81	0,84
	α/ε	1	0,23	1,16	0,32
Surface	A^s/A	Steady-State Temperature T_{av} (°C)			
Flat plate	1,00	125	1	140	26
Cylinder	0,32	26	-67	37	-48
sphere	0,25	8	-79	19	-61

HEAT REJECTION CAPABILITY OF DIFFERENT-SHAPED SATELLITE IN SPACE

The analysis of heat rejection capability is more meaningful when different satellite body structure radiative areas are same size. Dissipation in a satellite and environment heating values are also taken as identical. Basic thermal control can be illustrated as shown in Figure 2 by considering the main body of a satellite as an idealized thermal system with one dissipating interior region.

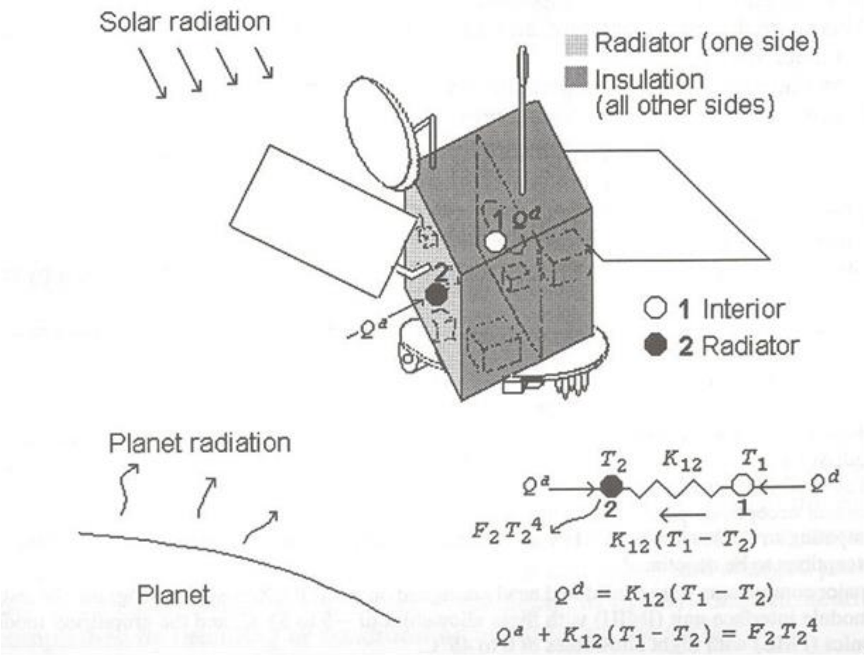


Figure 2: Method of satellite thermal control [Karam, 1998]

Then the energy balance in steady state is written

$$Q^d = K_{12}(T_1 - T_2) \tag{5}$$

and

$$Q^d + Q^a = F_2 T_2^4 \tag{6}$$

where K_{12} and F_2 are heat exchange factors. In equations (5) and 6, denoting interior dissipation by Q^d and the absorbed portion of environment heating by Q^a.

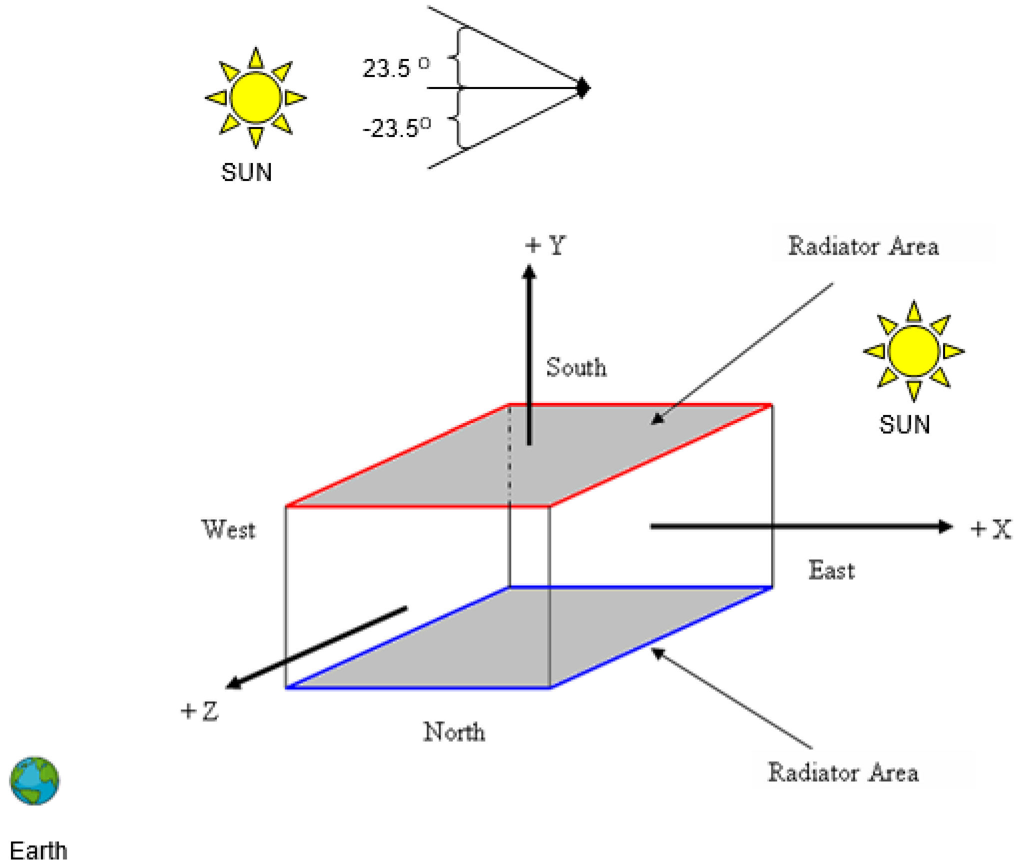
When there are no interactions with other surfaces in the space and the equation written

$$Q^d + \alpha^s q^s A^s + \alpha^s q^A A^A + \varepsilon q^E A^E = A^r \varepsilon \sigma T^4 \tag{7}$$

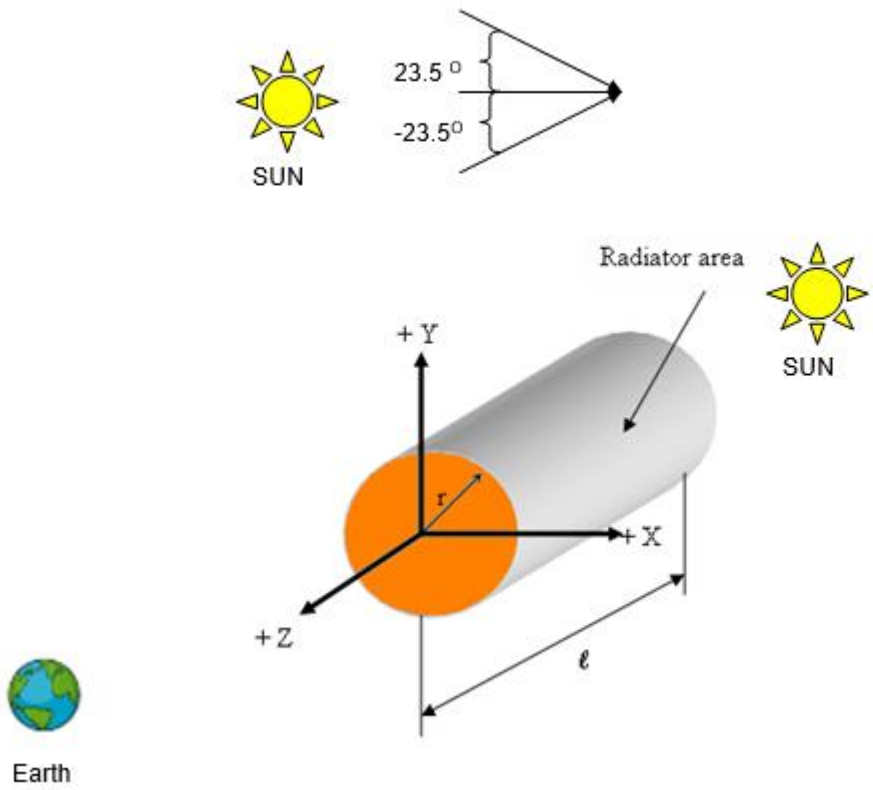
after IR emission (Earth flux q^E, W/m^2) and reflected sun (Albedo q^A, W/m^2) are neglected at GEO and then heat rejection capability at given radiator temperature with radiation to deep space gives

$$\frac{Q^d}{A^r} = \varepsilon \sigma T^4 - \left(\frac{A^s}{A^r}\right)\alpha^s q^s \tag{8}$$

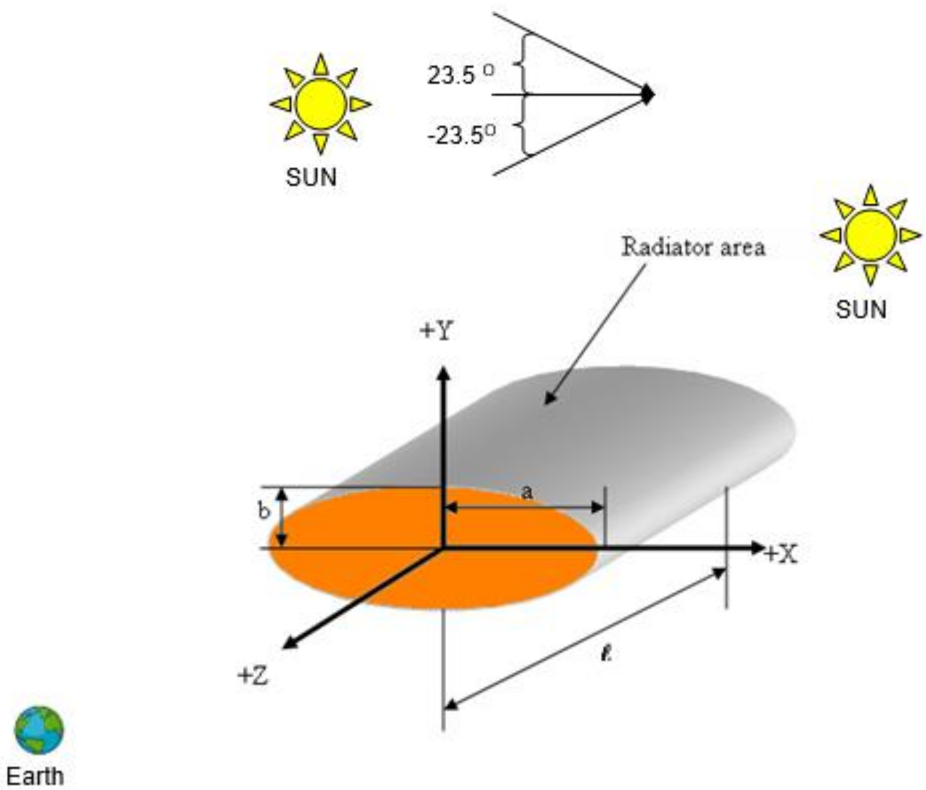
The equation (8) is applied to different spacecraft body structure which shown in Figure 3.



(a)



(b)



(C)

Figure 3: (a) *Rectangular-shaped, (b) cylinder-shape and (c) elliptical-shape satellites*

The heat rejection capability of each shape for satellite was calculated by equations (8). The values for the calculation were given in Table 4 and Table 5. The result is given in Table Table 6 and Table 7.

Table 4: Dimensions of spacecraft and thermal properties

Properties	**Values**
A^r	10 m^2
q_{ss}	1326 W/m^2
q_{ws}	1418 W/m^2
θ	23.5 deg
T_s	0 K
OSR	
α	0.27
ε	0.84

Table 5: Spacecraft dimension

Plate			**A^r**	**A^s**	**A^s/A^r**				
			m^2	m^2					
			10	5,00	0,5				
Cylinder	**r**	**l**	**A^r**	**A^s**	**A^s/A^r**				
	m	m	m^2	m^2					
	1	1,59	10	3,18	0,32				
Ellipse	**a/b**	**a**	**b**	**l**	**Ar**	**As a face Sun**	**As/Ar**	**As b face Sun**	**As/Ar**
		m	m	m	m2	m2		m2	
	2	2	1	1,06	10	4,24	0,42	2,12	0,21
	1,75	1,75	1	1,16	10	4,05	0,41	2,31	0,23
	1,5	1,5	1	1,27	10	3,82	0,38	2,55	0,25
	1	1	1	1,59	10	3,18	0,32	3,18	0,32

ANALYTICAL RESULTS AND DISCUSSION

The analytical results of heat rejection capability are shown in Table 6 and Table 7. Plate is the representation of rectangular or square satellite. Table 6 shows heat rejection capability at summer solstice. Table 7 shows heat rejection capability at winter solstice. The analytical results in Table 6 and Table 7 indicate that radiator temperature of the spacecraft affects heat rejection capability. For example, at 20 ^oC radiator temperature for cylinder spacecraft in Table 6, heat rejection capability is 306.28 W/m^2. At 40 ^oC radiator temperature, heat rejection capability is 412.54 W/m^2. It can be seen from the results that increased radiator temperature increases the heat rejection capability. Radiator area (A^r) and solar radiation area (A^s) of the satellite are a significant impact on the heat rejection capability. When heat rejection capability is calculated, A^s/A^r is the ratio that affects the results of heat rejection capability. A^s/A^r are listed in Table 5. The highest A^s/A^r is calculated for rectangular or square satellite. Heat rejection capability on rectangular satellite is lower than cylinder satellite. When A^s/A^r ratio increases, the heat rejection capability decreases. A^s/A^r for ellipse varies with dimensions. Therefore, heat rejection capability varies according to dimensions and A^s/A^r ratio. In Table 6 and 7, a and b shows lenghts in x and y direction, respectively. a/b shows the ratio.

Table 6: Heat rejection capability at given radiator temperature (Summer Solstice)

Plate		Cylinder		a/b=2 Ellipse		a/b=1,75 Ellipse		a/b=1,5 Ellipse		a/b=0,5 Ellipse	
T °C	Heat Rejection W/m²	T °C	Heat Rejection W/m²	T °C	Heat Rejection W/m²	T °C	Heat Rejection W/m²	T °C	Heat Rejection W/m²	T °C	Heat Rejection W/m²
-25	109,22	-25	135,14	-25	120,01	-25	122,77	-25	126,07	-25	150,31
-20	124,22	-20	150,14	-20	135,01	-20	137,77	-20	141,07	-20	165,31
-15	140,14	-15	166,05	-15	150,93	-15	153,68	-15	156,99	-15	181,23
-10	157,01	-10	182,92	-10	167,80	-10	170,55	-10	173,86	-10	198,09
-5	174,87	-5	200,78	-5	185,66	-5	188,41	-5	191,72	-5	215,95
0	193,75	0	219,67	0	204,55	0	207,30	0	210,60	0	234,84
5	213,71	5	239,62	5	224,50	5	227,25	5	230,56	5	254,79
10	234,77	10	260,68	10	245,56	10	248,31	10	251,62	10	275,85
15	256,97	15	282,88	15	267,76	15	270,51	15	273,82	15	298,06
20	280,36	20	306,28	20	291,15	20	293,90	20	297,21	20	321,45
25	304,98	25	330,89	25	315,77	25	318,52	25	321,83	25	346,06
30	330,87	30	356,78	30	341,66	30	344,41	30	347,72	30	371,95
35	358,07	35	383,98	35	368,86	35	371,61	35	374,92	35	399,15
40	386,63	40	412,54	40	397,42	40	400,17	40	403,48	40	427,71
45	416,59	45	442,50	45	427,38	45	430,13	45	433,44	45	457,67
50	447,99	50	473,91	50	458,78	50	461,54	50	464,84	50	489,08
55	480,89	55	506,81	55	491,68	55	494,44	55	497,74	55	521,98
60	515,33	60	541,24	60	526,12	60	528,87	60	532,18	60	556,41

Table 7: Heat rejection capability at given radiator temperature (Winter Solstice)

Plate		Cylinder		a/b=2 Ellipse		a/b=1,75 Ellipse		a/b=1,5 Ellipse		a/b=0,5 Ellipse	
T °C	Heat Rejection W/m²	T °C	Heat Rejection W/m²	T °C	Heat Rejection W/m²	T °C	Heat Rejection W/m²	T °C	Heat Rejection W/m²	T °C	Heat Rejection W/m²
-25	104,27	-25	131,98	-25	115,81	-25	118,75	-25	122,29	-25	148,20
-20	119,27	-20	146,98	-20	130,81	-20	133,75	-20	137,29	-20	163,21
-15	135,19	-15	162,90	-15	146,73	-15	149,67	-15	153,21	-15	179,12
-10	152,06	-10	179,77	-10	163,60	-10	166,54	-10	170,08	-10	195,99
-5	169,92	-5	197,63	-5	181,46	-5	184,40	-5	187,93	-5	213,85
0	188,80	0	216,52	0	200,34	0	203,29	0	206,82	0	232,74
5	208,76	5	236,47	5	220,29	5	223,24	5	226,77	5	252,69
10	229,81	10	257,53	10	241,35	10	244,30	10	247,83	10	273,75
15	252,02	15	279,73	15	263,56	15	266,50	15	270,04	15	295,95
20	275,41	20	303,12	20	286,95	20	289,89	20	293,43	20	319,34
25	300,03	25	327,74	25	311,57	25	314,51	25	318,04	25	343,96
30	325,91	30	353,63	30	337,45	30	340,40	30	343,93	30	369,85
35	353,12	35	380,83	35	364,66	35	367,60	35	371,13	35	397,05
40	381,67	40	409,39	40	393,21	40	396,16	40	399,69	40	425,61
45	411,63	45	439,35	45	423,17	45	426,12	45	429,65	45	455,57
50	443,04	50	470,75	50	454,58	50	457,52	50	461,06	50	486,98
55	475,94	55	503,65	55	487,48	55	490,42	55	493,96	55	519,87
60	510,37	60	538,09	60	521,91	60	524,86	60	528,39	60	554,31

CONCLUSION

Table 2 and Table 3 gives the results of temperatures on different shape radiators of a satellite with different materials at summer and winter solstice in GEO. Solar impingement is only source environment heating. It can be seen in Table 2 and Table 3 that sphere shape has the lowest temperature with any type of materials. The highest temperature is reached at flat plate shape.

Table 6 and Table 7 give the results of heat rejection capability at given radiator temperature. It is clear from the relative value in Table 6 and Table 7 that cylinder satellite radiator has a higher heat rejection than rectangular satellite. On the other hand, heat rejection capability of ellipse satellite varies with the dimensions. In order to have a high value of heat rejection capability from ellipse satellite, optimized radiator design needs to be exercised with respect to ratio of a/b. It is possible to reach at the highest heat rejection capability with ellipse satellite.

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